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Tuning of electrical properties of In_xO_y thin films grown by MOCVD for different applications

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Indium oxide is a very important material for microelectronic applications. It is a transparent semiconducting wide band gap (~ 3.6 eV) oxide material, which is n-type. Various methods for the preparation of In_2O_3 films like evaporation [1] and sputtering [2] are described in the literature. With such technologies, a variety of electrical properties of In_2O_3 thin films can be obtained (metallic, semiconducting, or insulating behavior). Thin highly conducting In_2O_3 films are widely used as transparent electrodes in optoelectronic devices, i.e. flat-panel displays [3] and solar cells [4]. The highly resistive In_2O_3 thin films are widely used in gas detectors [2], especially in ozone (O_3) sensors [2].

Here, we report on a method of the deposition of In_xO_y films with the tunable properties by MOCVD for different applications. The In_xO_y films were deposited in a horizontal MOCVD reactor (AIX200) on c-plane Al_2O_3 substrates. TMIn and H_2O have been used, respectively, as indium and oxygen sources.

The electrical measurements at room-temperature showed the strong change in the electrical properties of the In_xO_y films (Fig. 1). The sheet electron density of the In_xO_y films decreased more than one order of magnitude, from $5.3*10^{14}$ cm^{-2} at 300°C to $4.5*10^{13}$ cm^{-2} at 500°C. At the same time, the special resistance increased about two orders of magnitude, from $3.8*10^{-3}$ Ωcm at 300°C to

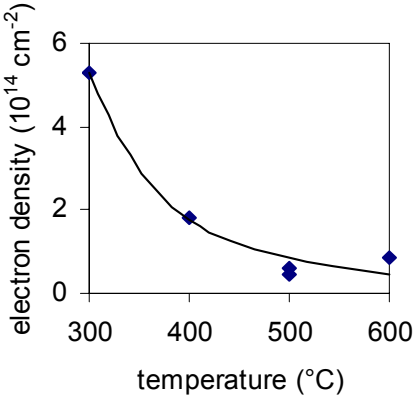

Fig. 1: Dependence of electron density of In_xO_y films on the substrate temperatures.

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$2.5*10^{-1}$ Ωcm at 500°C. Furthermore, the films deposited at 300°C are degenerated as observed by temperature dependent measurements because the electron concentration increased only slightly (~40%) from liquid-nitrogen temperature to 270°C.

Optical transmission measurements were carried out on 60 nm thick films deposited at 300°C. The films have a transmittance of over 85% in the visible region (wavelength from 400 to 760 nm). From the points mentioned above, the films are suitable for applications as transparent conducting electrodes.

The films deposited at high substrate temperatures are more resistive than those deposited at low temperatures. They are assumed to be applied in gas sensors, for example for O_3. The resistance change of the In_xO_y film deposited at 600°C is shown in Fig. 2. The sample was annealed at 1100°C 30 s in oxygen atmosphere before measurements. The film was first exposed by UV-light (photoreduction). Then, it was exposed to O_2 or O_3 atmosphere (oxidation). The resistance changes only slightly, from about 2 kΩ after photoreduction to 6.6 kΩ after O_2 exposure, while the resistance changes 20 times up to 40 kΩ after O_3 exposure.

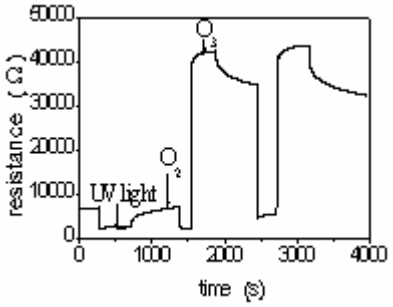

Fig. 2: Photoreduction and subsequent oxidation by O_2 and O_3 of In_xO_y film deposited at 600°C.

In conclusion, we have reported on the tuning of electrical properties of In_xO_y films grown by MOCVD. The films deposited at low substrate temperatures are degenerated and transparent in the visible range. So, they are suitable to work as conducting transparent electrodes. The films deposited at high substrate temperatures are more resistive and are suitable for gas sensors. It is feasible to grow In_xO_y films only using MOCVD for different applications.

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